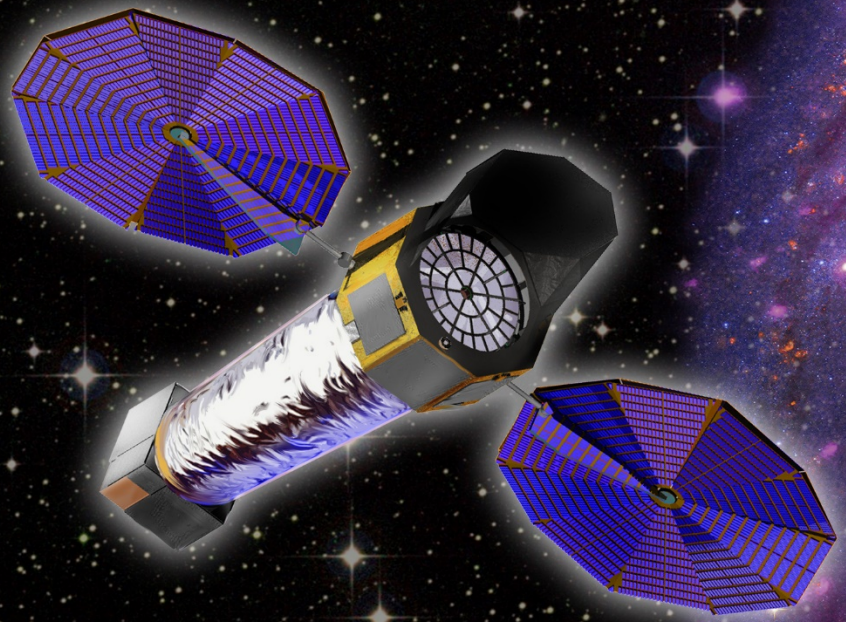
Lynx and Exoplanet Science

Rachel Osten, STScI & JHU



X-RAY OBSERVATORY

LYNX

X-RAY OBSERVATORY
LYNX

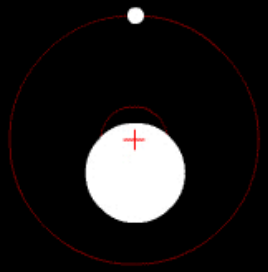
Lynx and Exoplanets

- What is Exoplanet Science?
- What is Lynx?
- How/what can we measure with Lynx?
- Potential exoplanet applications with Lynx

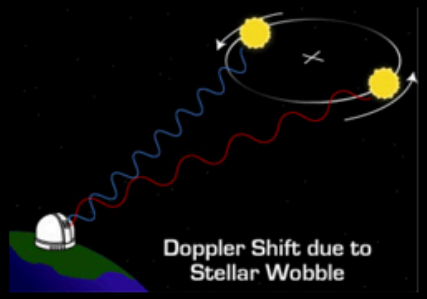
X-RAY OBSERVATORY

LYNX

What is Exoplanet Science?



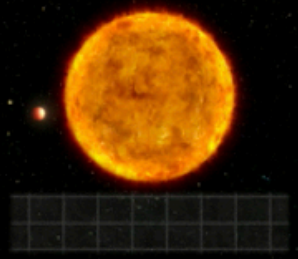
radial velocity — velocity shift of a star due to star+planet



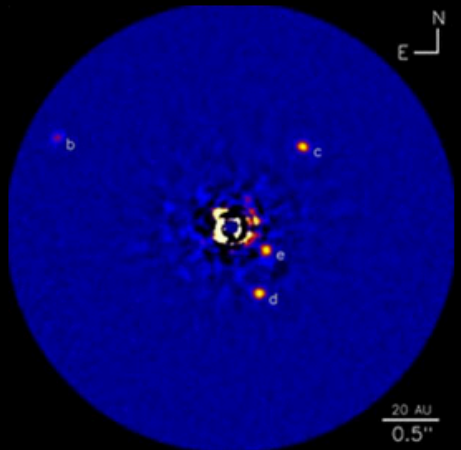
astrometry — seeing the reflex motion of the star due to star+planet system

transit — decrease in stellar light

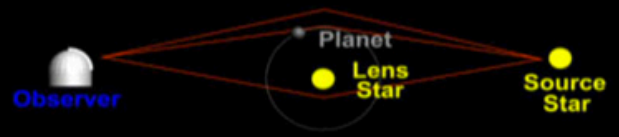
Not just this



direct imaging — block out the light of the star to see the planet directly

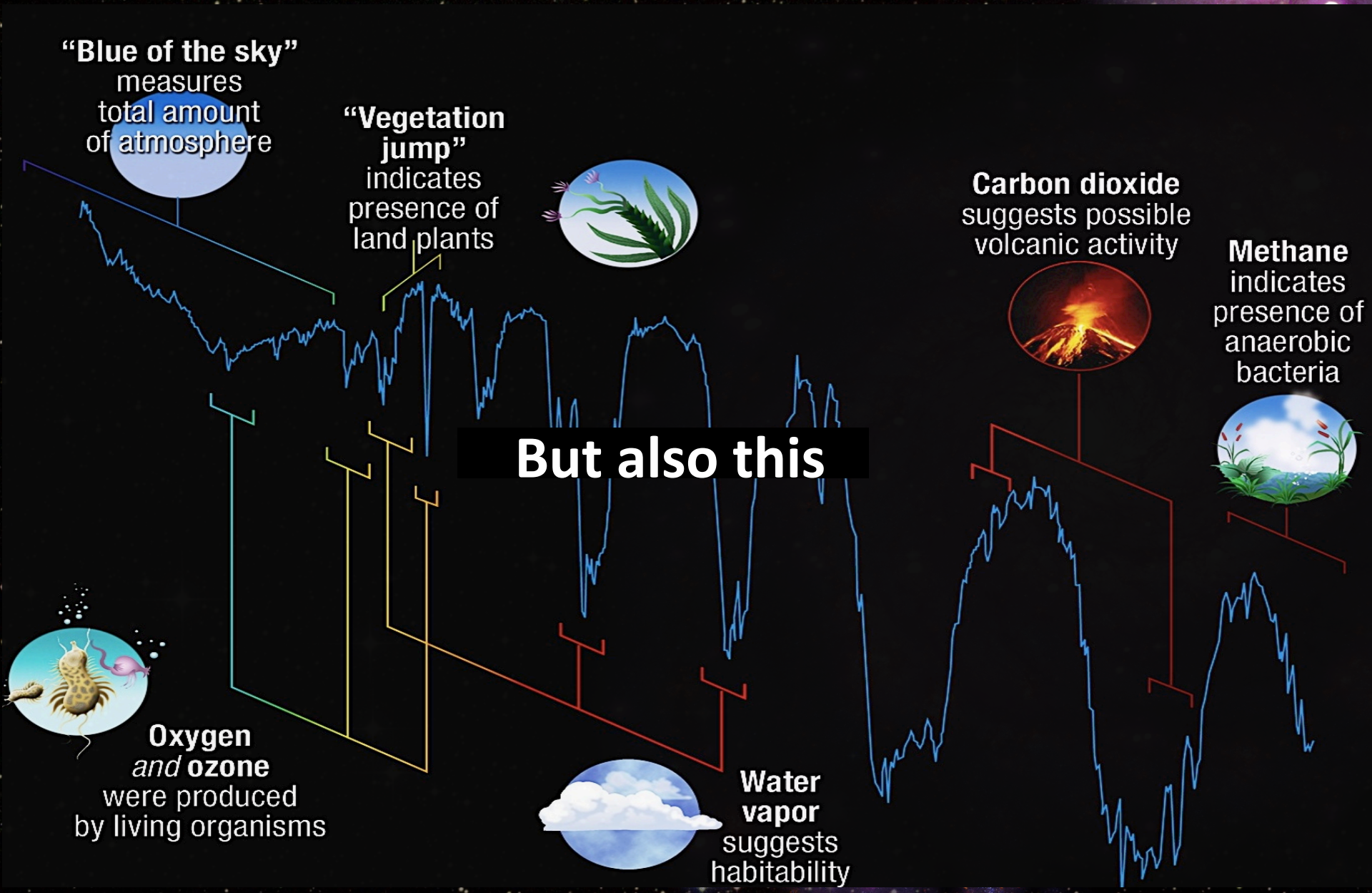


microlensing — gravitational lensing due to star+planet system passing in front of a background star



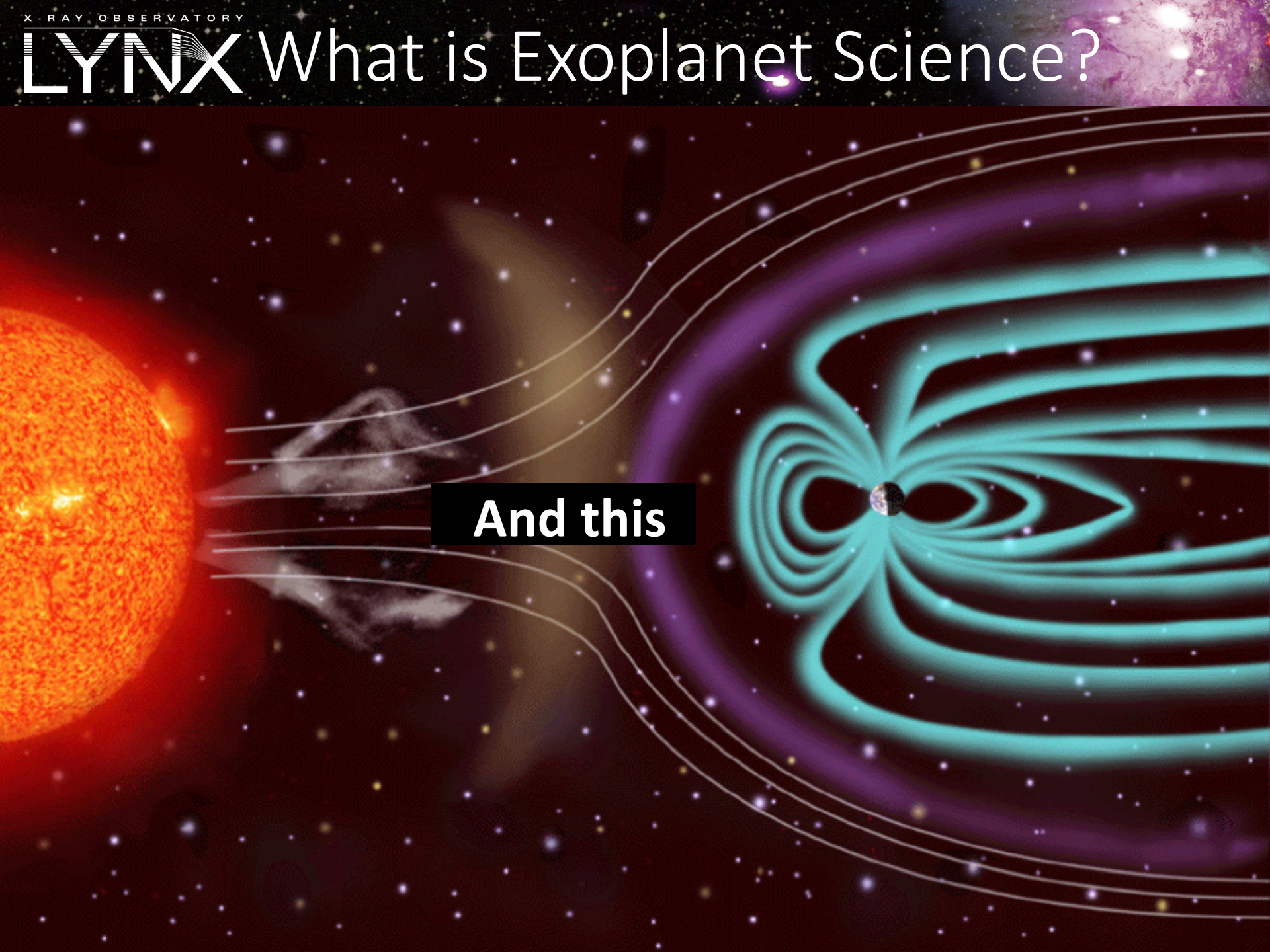
X-RAY OBSERVATORY
LYNX

What is Exoplanet Science?



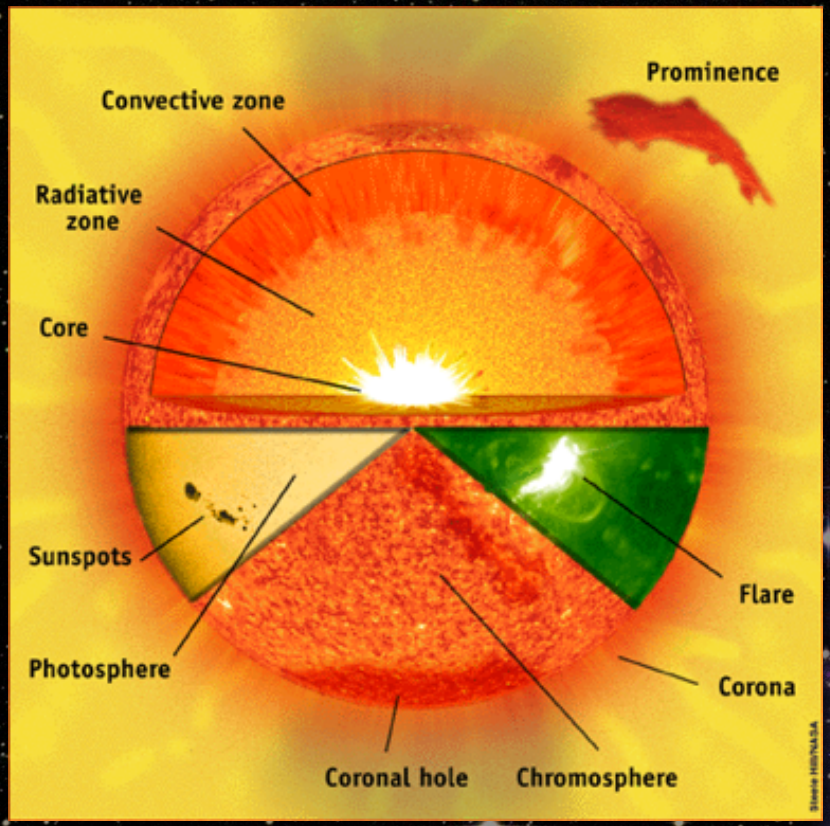
X-RAY OBSERVATORY
LYNX

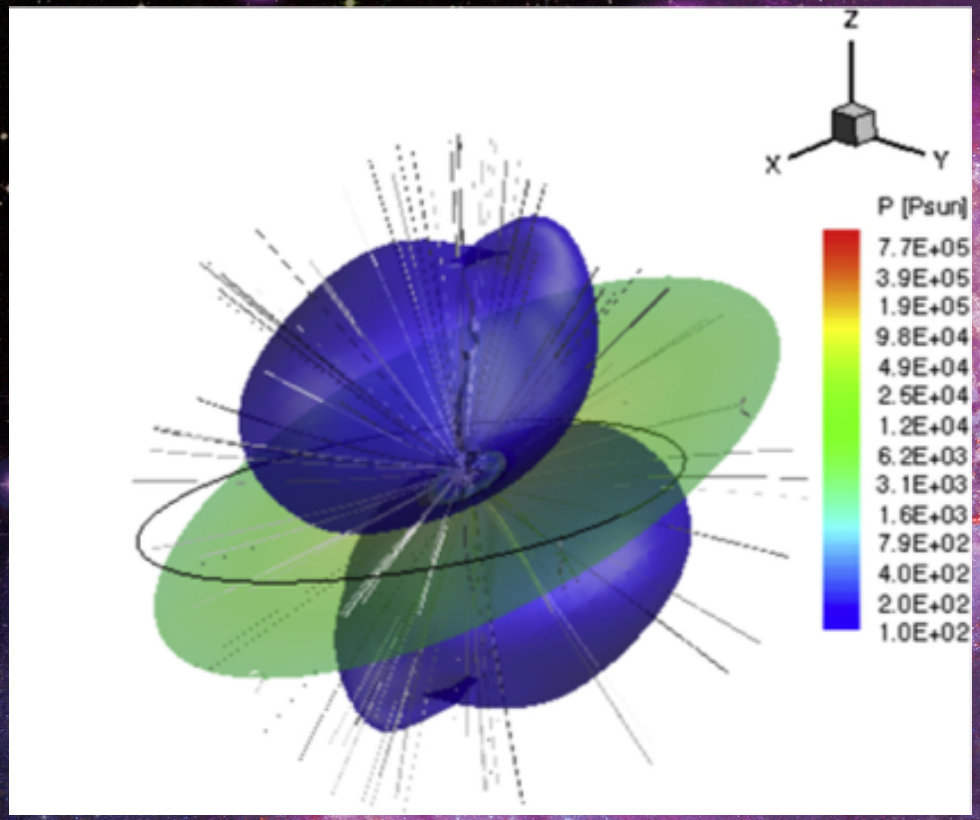
What is Exoplanet Science?



X-RAY OBSERVATORY
LYNX

What is Exoplanet Science?





The star's magnetic field creates an ecosystem which helps to set the environment that planets (and life) experience (Lingam & Loeb 2018)
Stellar magnetospheres influence the inner edge of the traditional habitable zone (Garaffo et al. 2016, 2017).

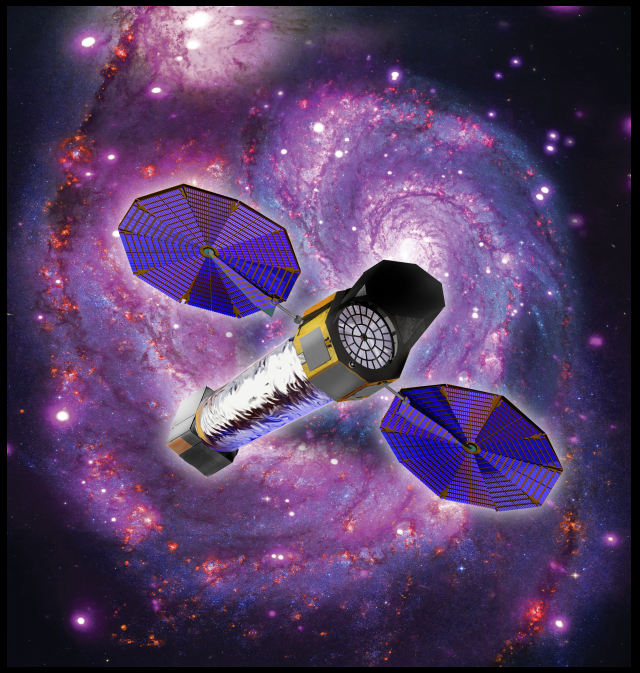
X-RAY OBSERVATORY
LYNX

What is Lynx?

One of 4 large missions under study for the 2020 Astrophysics Decadal, Lynx is an X-ray observatory that will directly observe the dawn of supermassive black holes, reveal the invisible drivers of galaxy and structure formation, and trace the energetic side of stellar evolution and stellar ecosystems.

Lynx will provide unprecedented X-ray vision into the "Invisible" Universe with leaps in capability over *Chandra* and *ATHENA*:

- 50–100× gain in sensitivity via high throughput with high angular resolution
- 16× field of view for arcsecond or better imaging
- 10–20× higher spectral resolution for point-like and extended sources

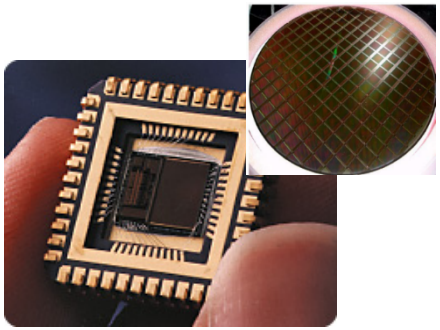


Lynx will contribute to nearly every area of astrophysics and provide synergistic observations with future-generation ground-based and space-based observatories, including gravitational wave detectors.

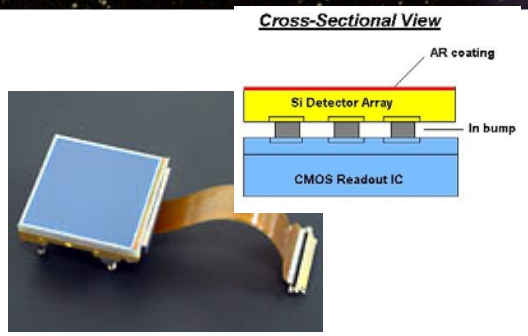
Lynx Instrument Suite

High Definition X-ray Imager (HDXI)

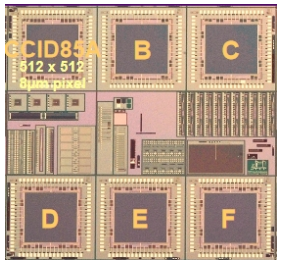
0.3" pixels, 20'x20' FOV
100 eV resolution 0.1-10 keV band



Monolithic CMOS



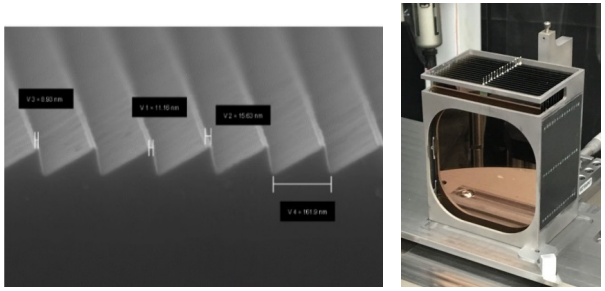
Hybrid CMOS



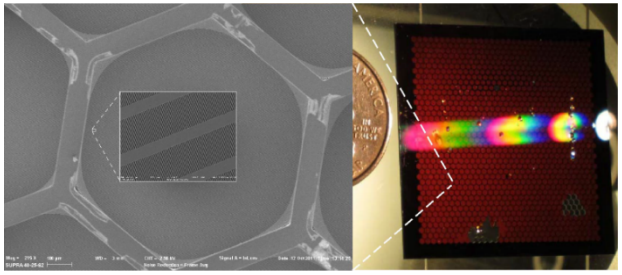
Digital CCD with CMOS readout

X-Ray Grating Spectrometer (XGS)

R>5000, A>4000 cm^2,
covers transitions of C, O, Mg, Ne, and Fe-L



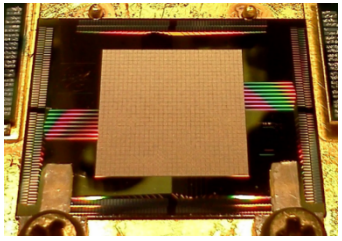
Off-Plane Grating Array

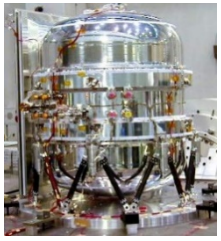


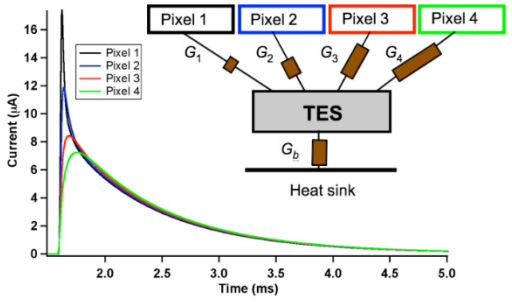
Critical Angle Transmission Grating Array

Lynx X-ray Microcalorimeter (LXM)

3 eV energy resolution
0.2-7 keV band
1" pixels 5'x5' FOV
Also: sub-arcsec imaging, 0.3 eV E resolution, 20'x20' FOV



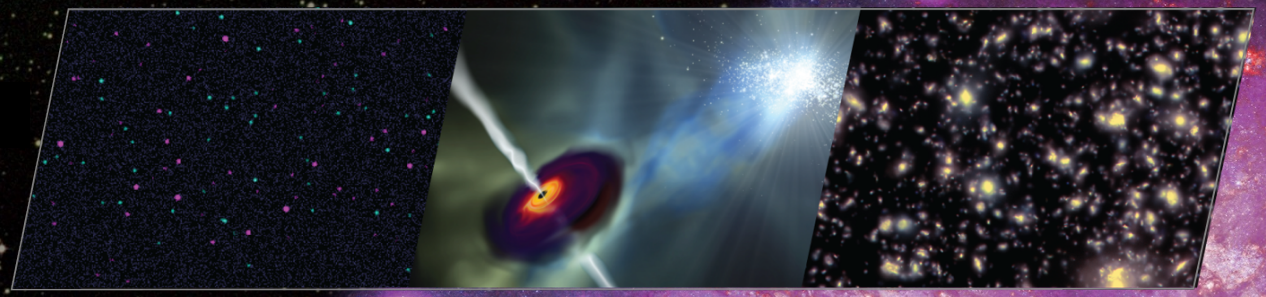




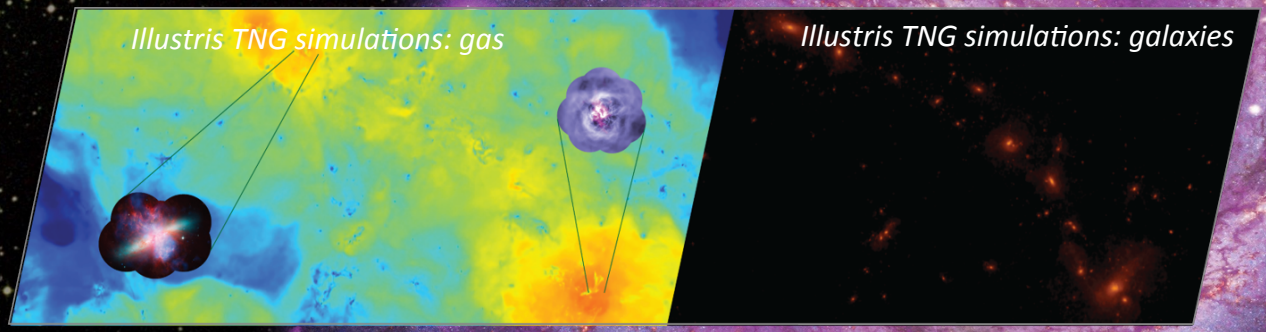
X-RAY OBSERVATORY
LYNX

The Science of Lynx

The Dawn of Black Holes



The Invisible Drivers of Galaxy and Structure Formation



The Energetic Side of Stellar Evolution and Stellar Ecosystems

Endpoints of stellar evolution

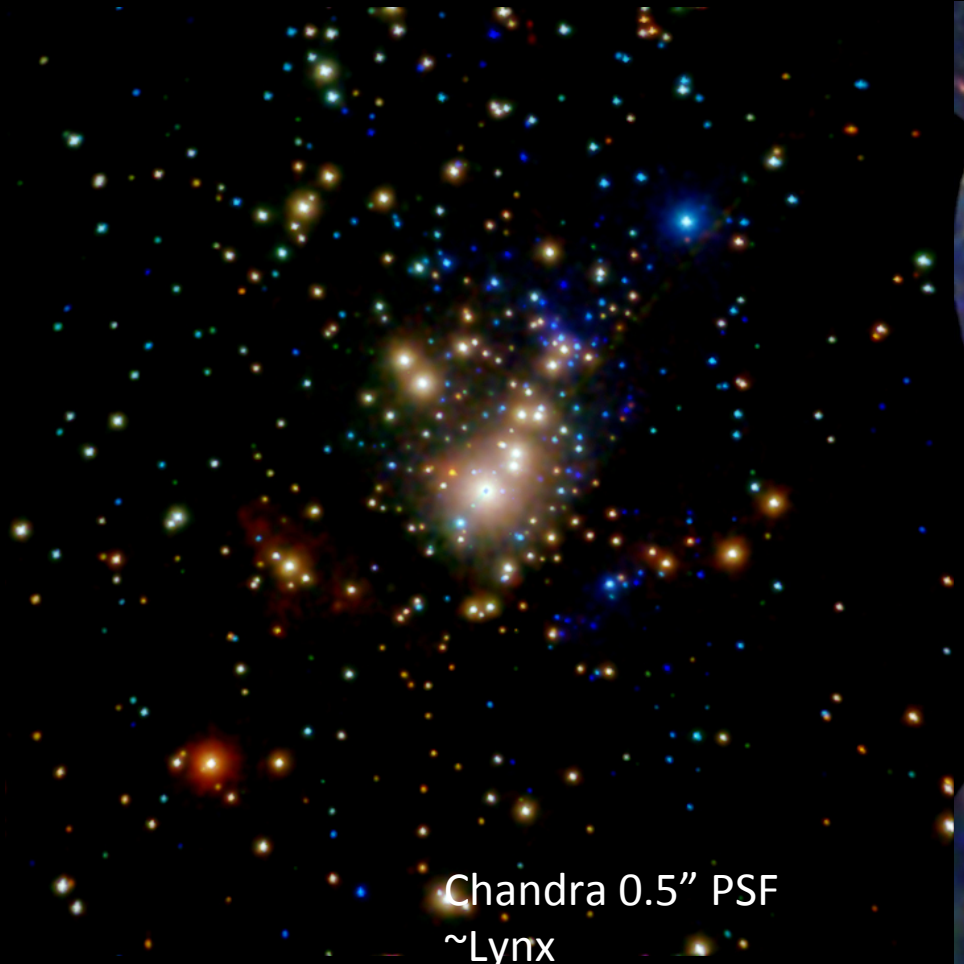
Stellar birth, coronal physics, feedback

Impact of stellar activity on habitability of planets

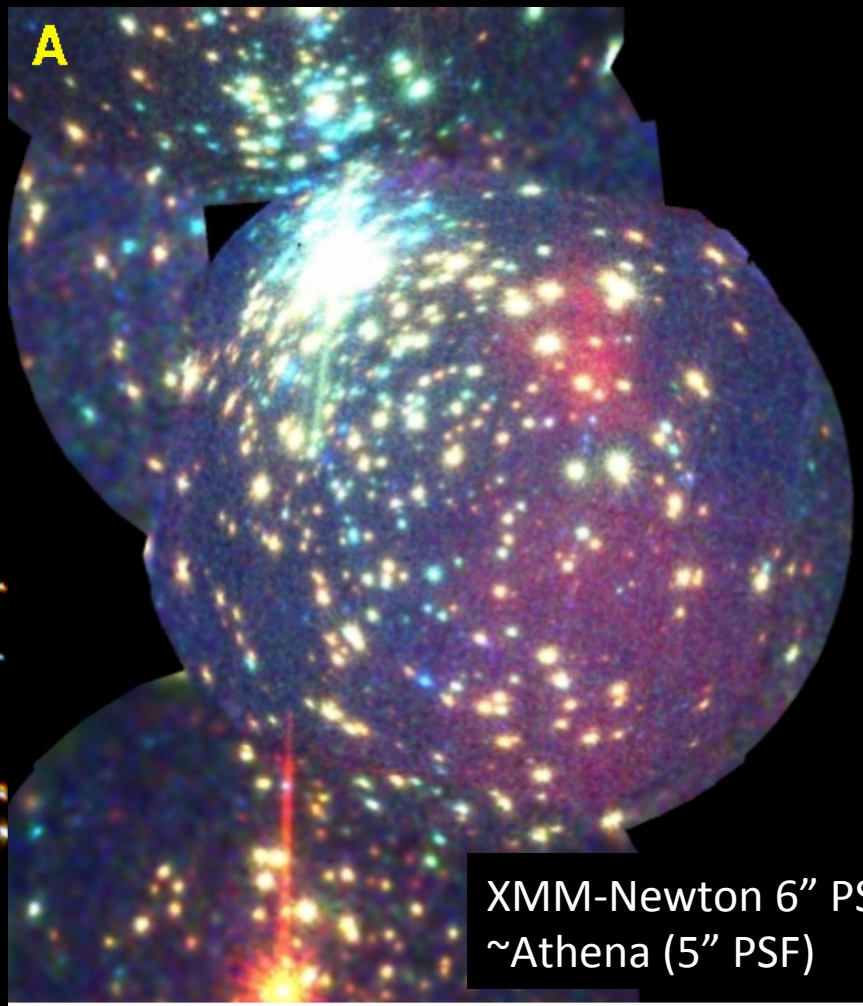
X-RAY OBSERVATORY
LYNX

How/What Can We Measure with Lynx?

- Crisp X-ray images w/ability to separate sources (0.5” PSF) and study diffuse emission
- Spatially resolved spectroscopy of point and diffuse emission
- Temporally resolve emission
- Good quality grating spectra with ability to measure key line diagnostics



Chandra 0.5” PSF
~Lynx

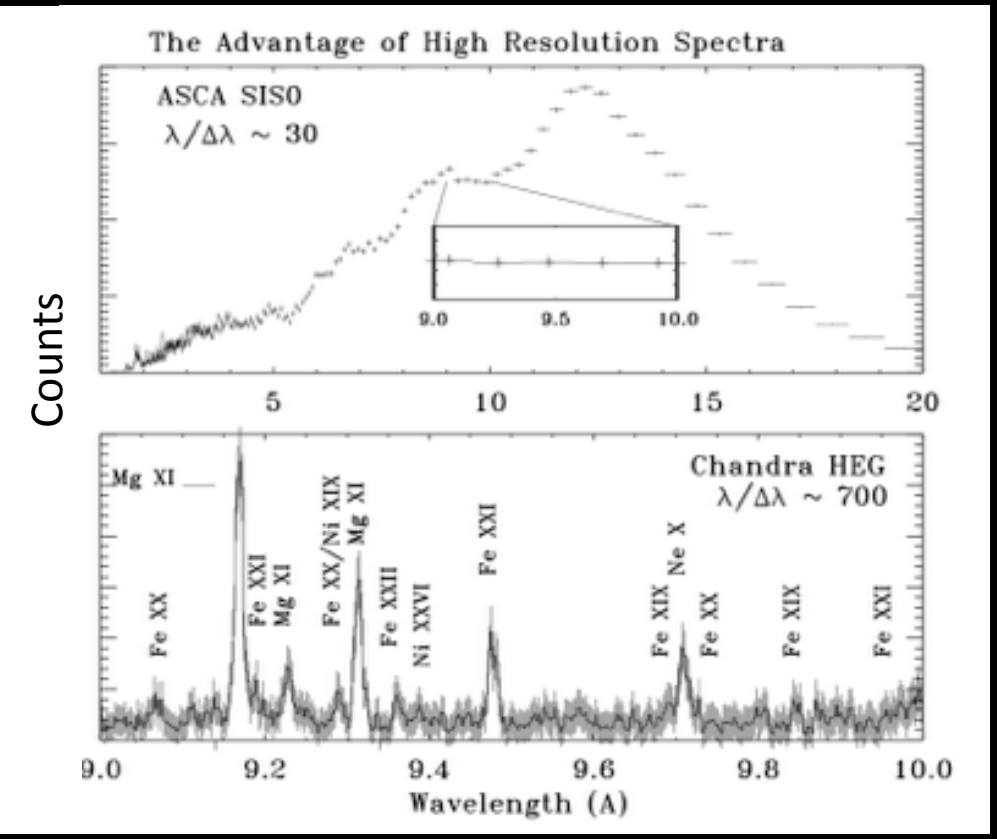


XMM-Newton 6” PSF
~Athena (5” PSF)

PIC

How/What Can We Measure with Lynx?

Good quality grating spectra with ability to measure key line diagnostics
X-ray spectrum is rich with diagnostics relevant to understanding how stars influence planets



Osten (2002)

The bulk of stellar X-ray spectra look like this (using energy resolution of CCDs)

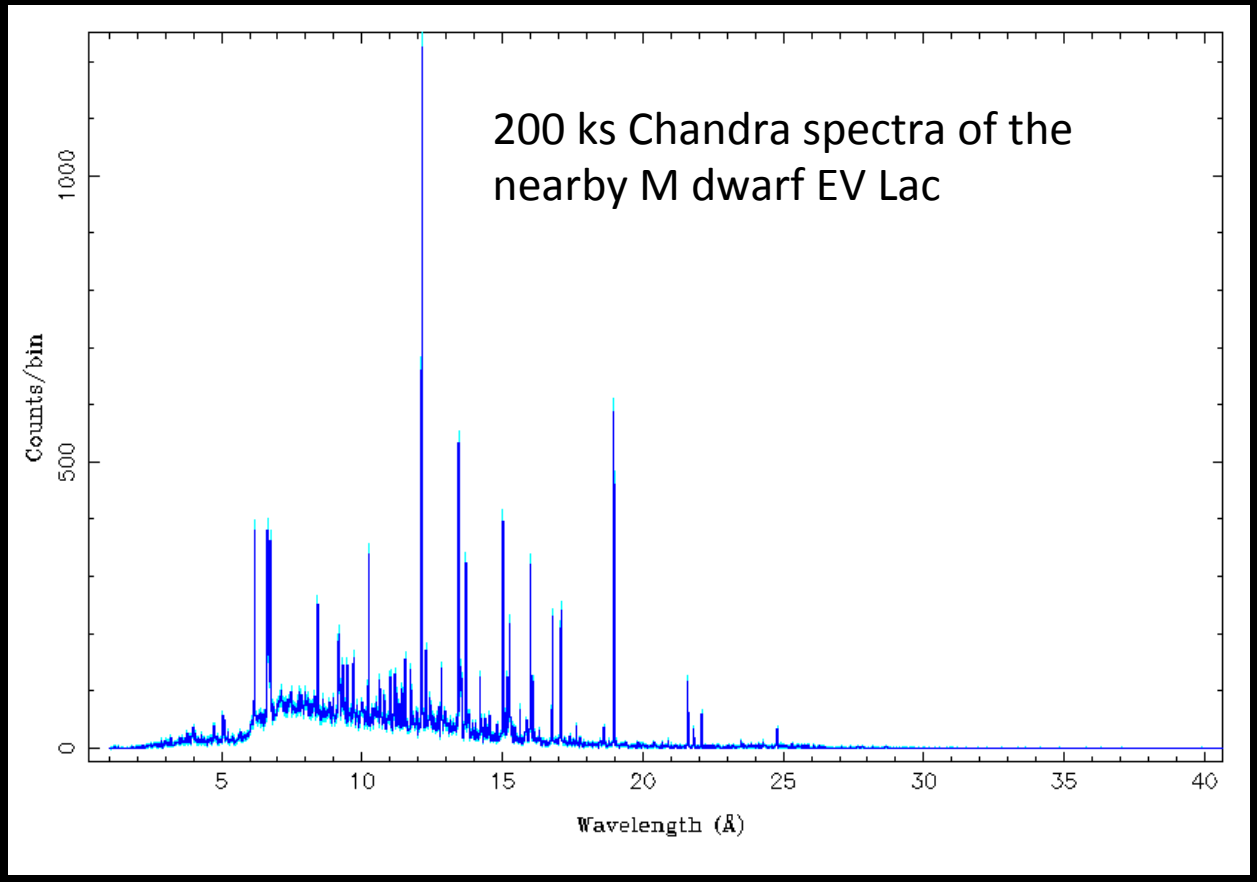
With Chandra's gratings we can obtain spectra like this

But only for the brightest cool stars.
In practice, only ~65 spectra in the Chandra archive, after nearly 20 years in space.
Known biases of L_x with T_x means we have the best measurements of only the hottest coronae

How/What Can We Measure with Lynx?

Temperatures

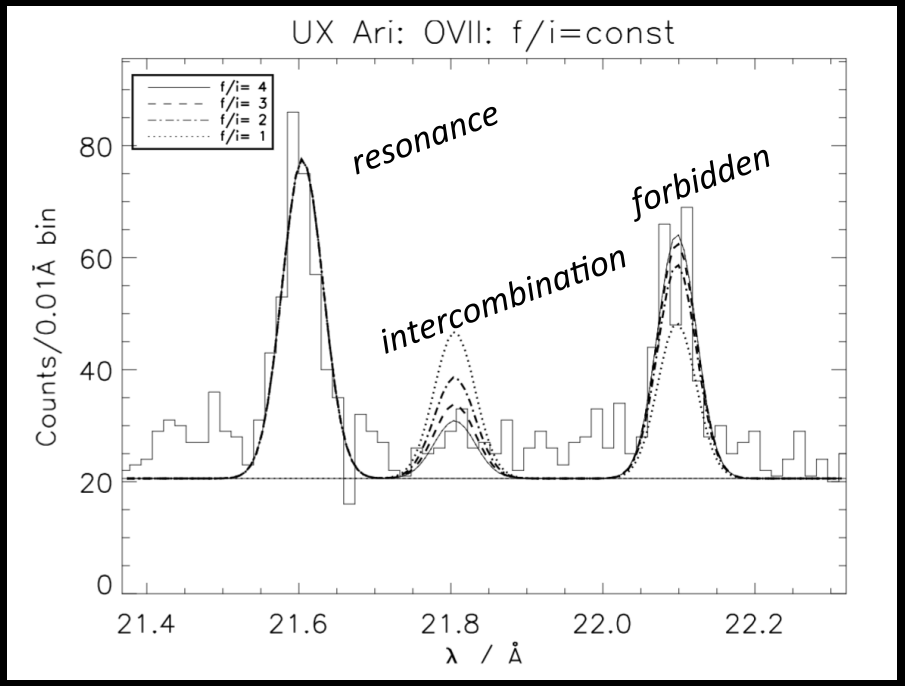
Giant leap forward for X-ray spectra of stars: 2.8 cm^2 of collecting area with Chandra at 22 Å, >4000 cm^2 with Lynx (and R>5000 compared with R of ~1000)

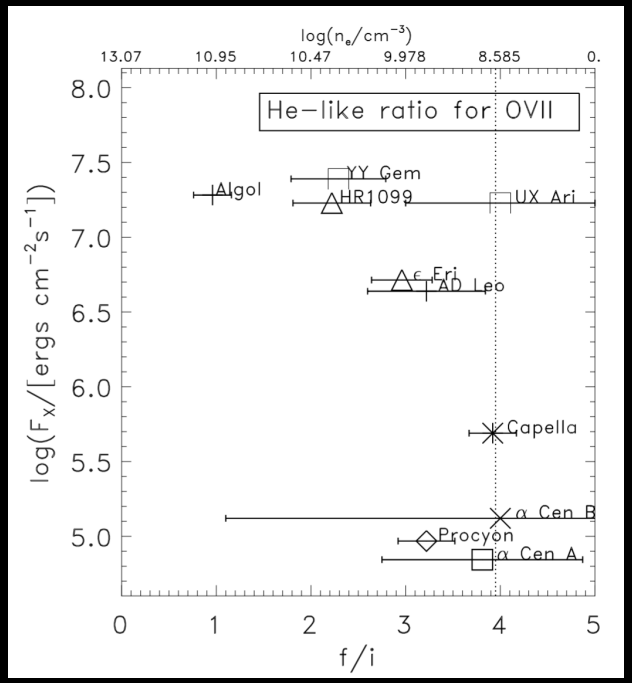


How/What Can We Measure with Lynx?

Densities

Need ability to resolve lines from nearby blends, underlying continuum
Densities enable constraints on length scales, dynamics



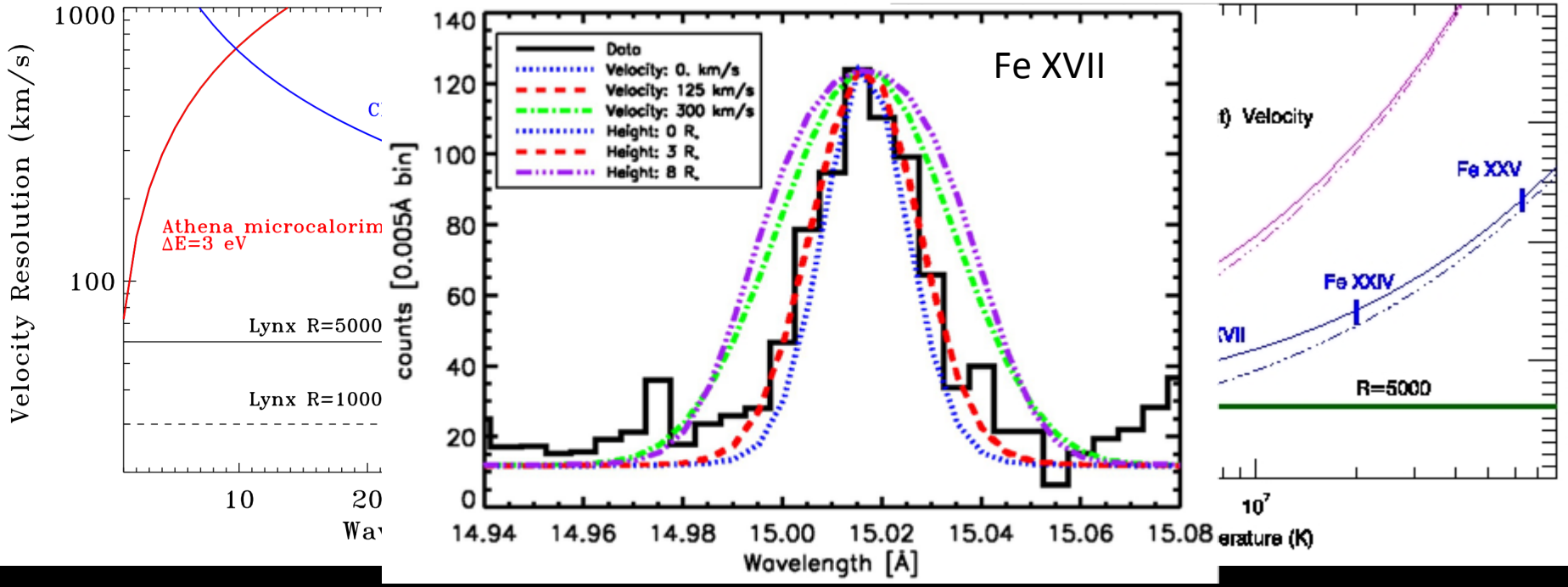


Ness et al. (2002)

How/What Can We Measure with Lynx?

Velocities

Resolving each line enables investigations of coronal dynamics, broadening mechanisms



Chung et al. (2004) excess broadening of Algol interpreted as rotational broadening from a radially extended corona

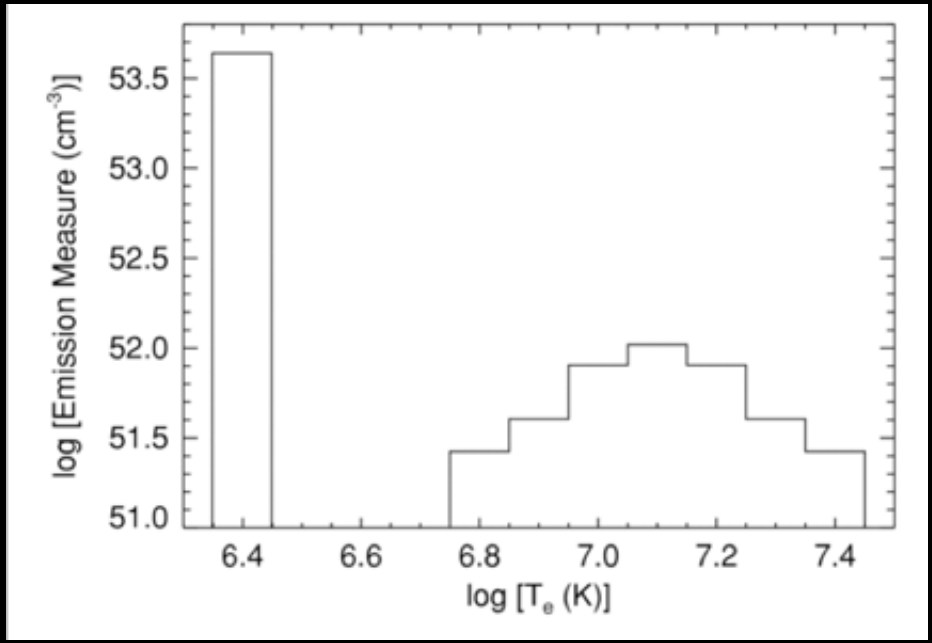
Figure courtesy of N. Brickhouse

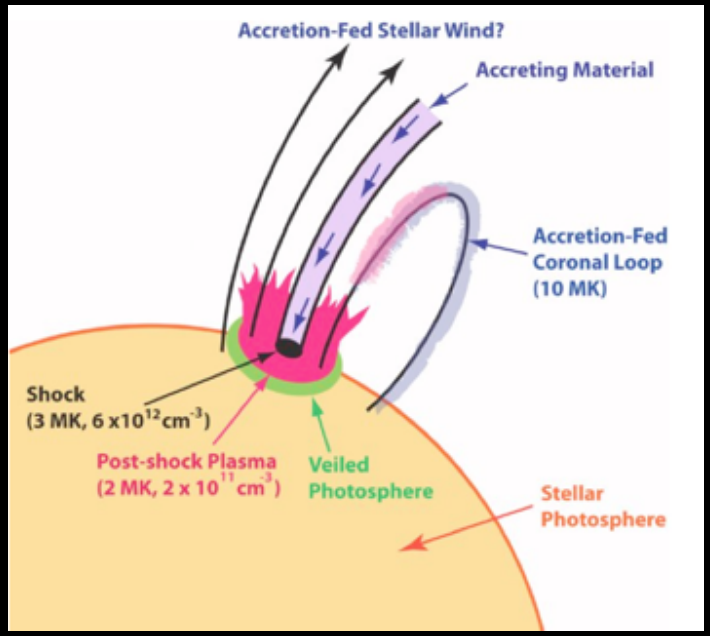
X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

Where do planets form? Where do they migrate?

- X-ray spectra of young stars show more than accretion plus magnetic activity
- X-rays implicated in rapid heating of protoplanetary disks
- After stars lose their disks X-ray surveys are the only way to find young stellar objects





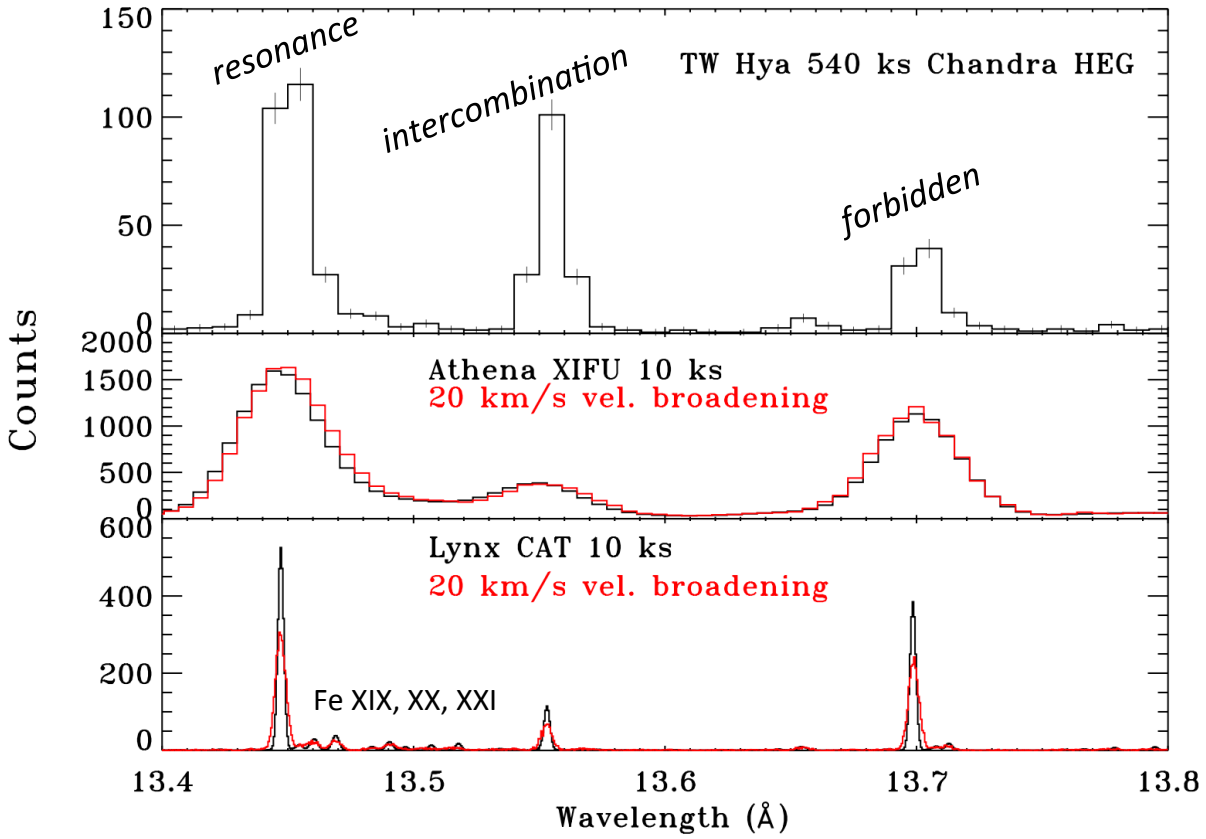
Brickhouse et al. (2010)

The impact of a high quality X-ray spectrum: need more than accretion source + coronal source to explain all the miriad diagnostics (electron density, electron temperature, absorbing column)

Potential Exoplanet Applications of Lynx

Where do planets form? Where do they migrate?

- X-ray spectra of young stars show more than accretion plus magnetic activity
- X-rays implicated in rapid heating of protoplanetary disks
- After stars lose their disks X-ray surveys are the only way to find young stellar objects



One of the deepest, highest resolution X-ray spectra of a young star ever taken

Athena issues
-- continuum placement for measurement of triplet lines
--blending lines

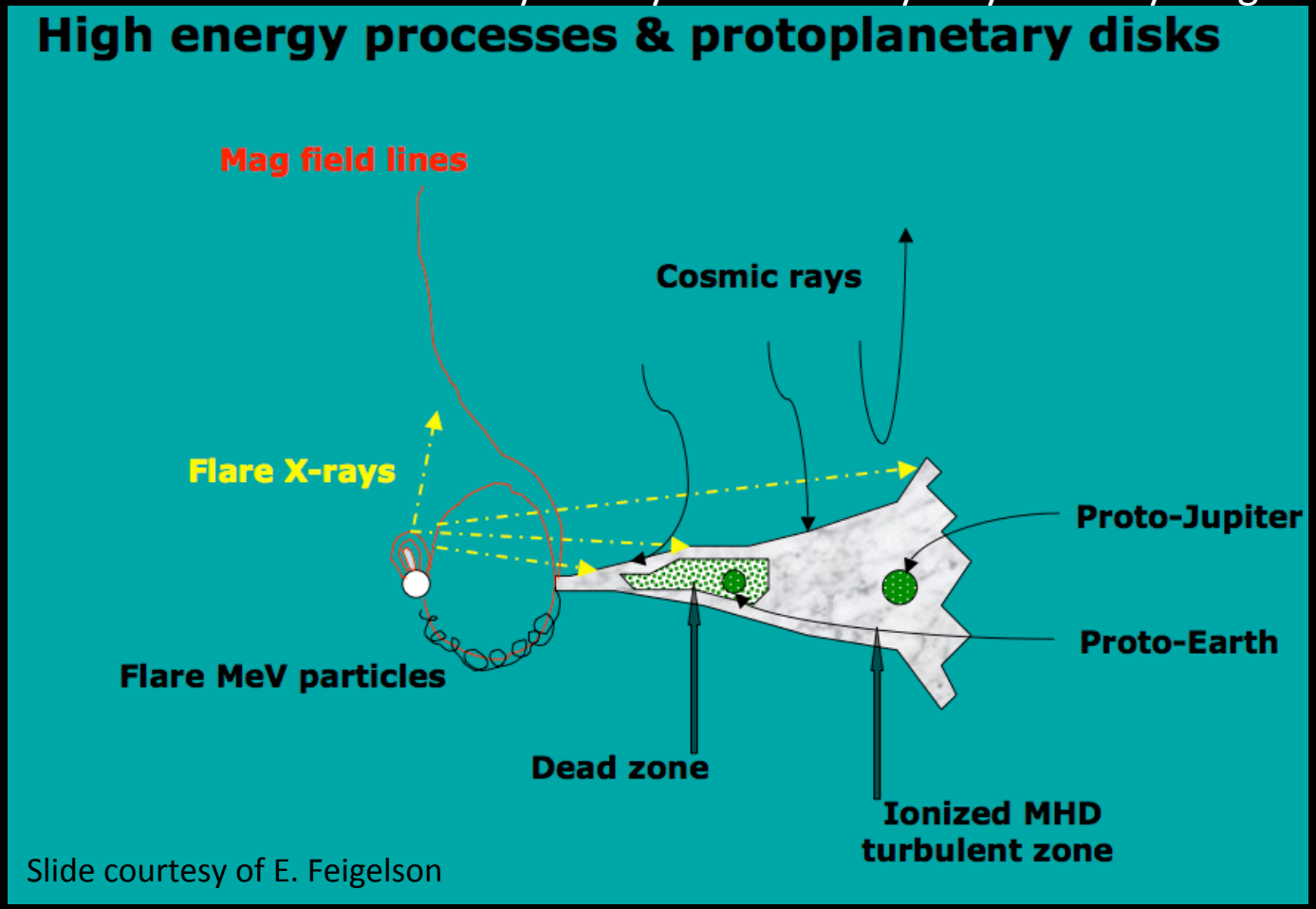
Lynx
--similar quality to Chandra exposure in 1 ks in Taurus-Auriga objects, 10 ks at Orion

X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

Where do planets form? Where do they migrate?

- X-ray spectra of young stars show more than accretion plus magnetic activity
- X-rays implicated in rapid heating of protoplanetary disks
- After stars lose their disks X-ray surveys are the only way to find young stellar objects

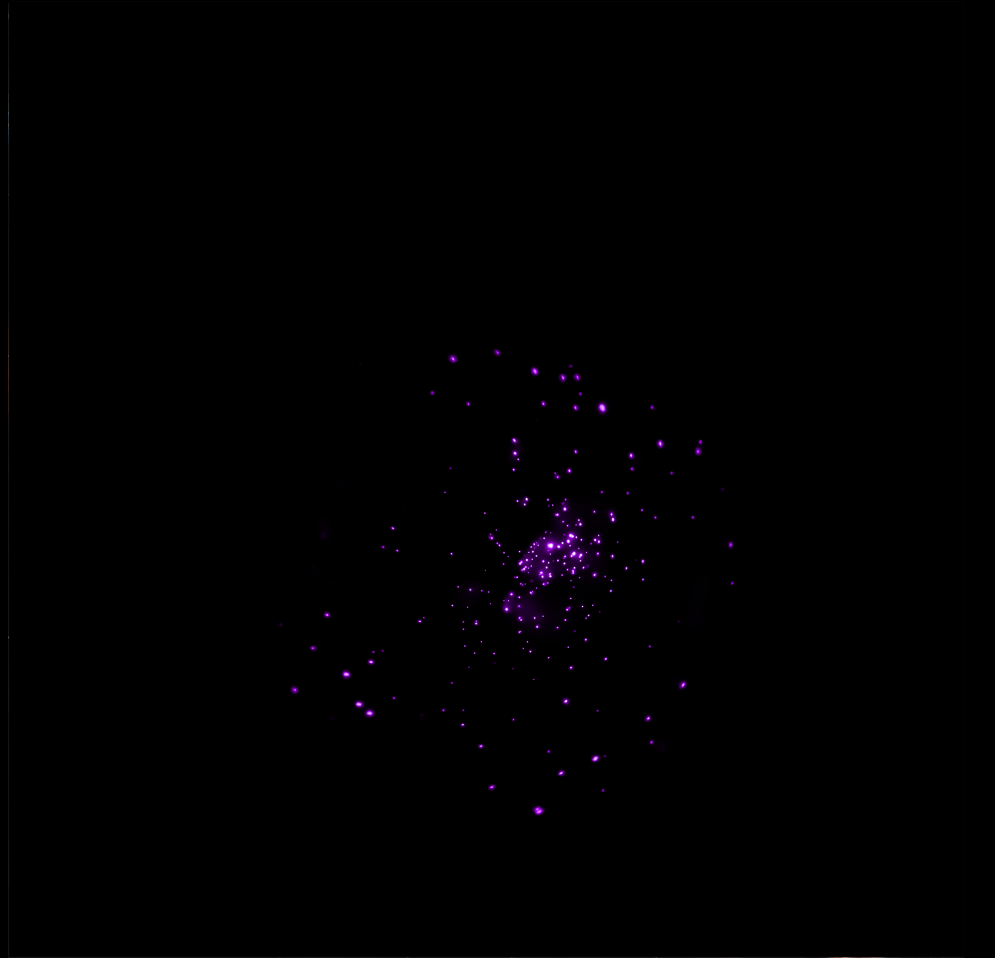


X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

Where do planets form? Where do they migrate?

- X-ray spectra of young stars show more than accretion plus magnetic activity
- X-rays implicated in rapid heating of protoplanetary disks
- After stars lose their disks X-ray surveys are the only way to find young stellar objects

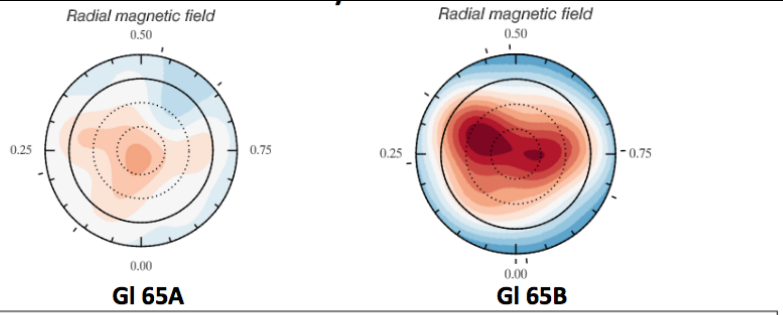


X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

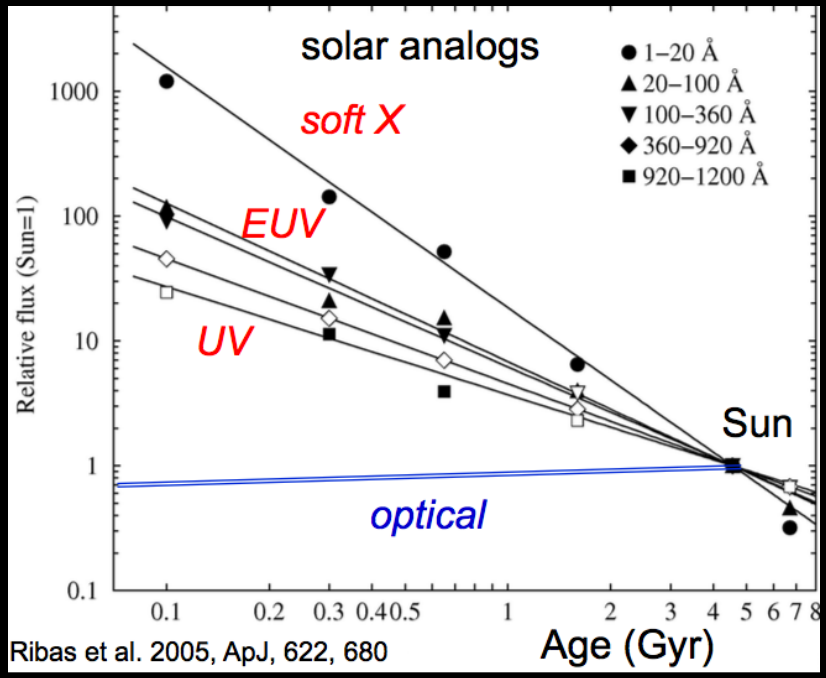
How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly



	Gl 65A	Gl 65B
Spectral class	M5.5Ve	M6Ve
Mass	0.1225 $M_\odot$	0.1195 $M_\odot$
Radius	0.165 $R_\odot$	0.159 $R_\odot$
Rot. vsini	28.5 km/s	30.6 km/s
Rot. period	5.86 hr	5.45 hr
Metall. [Fe/H]	-0.03	-0.12
<Bf> Stokes I	**5.2 kG**	**6.7 kG**
B_{dip} strength V	**0.3 kG**	**1.3 kG**
	complex, non-axisymmetric	**axisymmetric dipole**

Kervella et al. 2016, Barnes et al. 2016, Kochukhov et al. 2017, Lynch et al. 2017

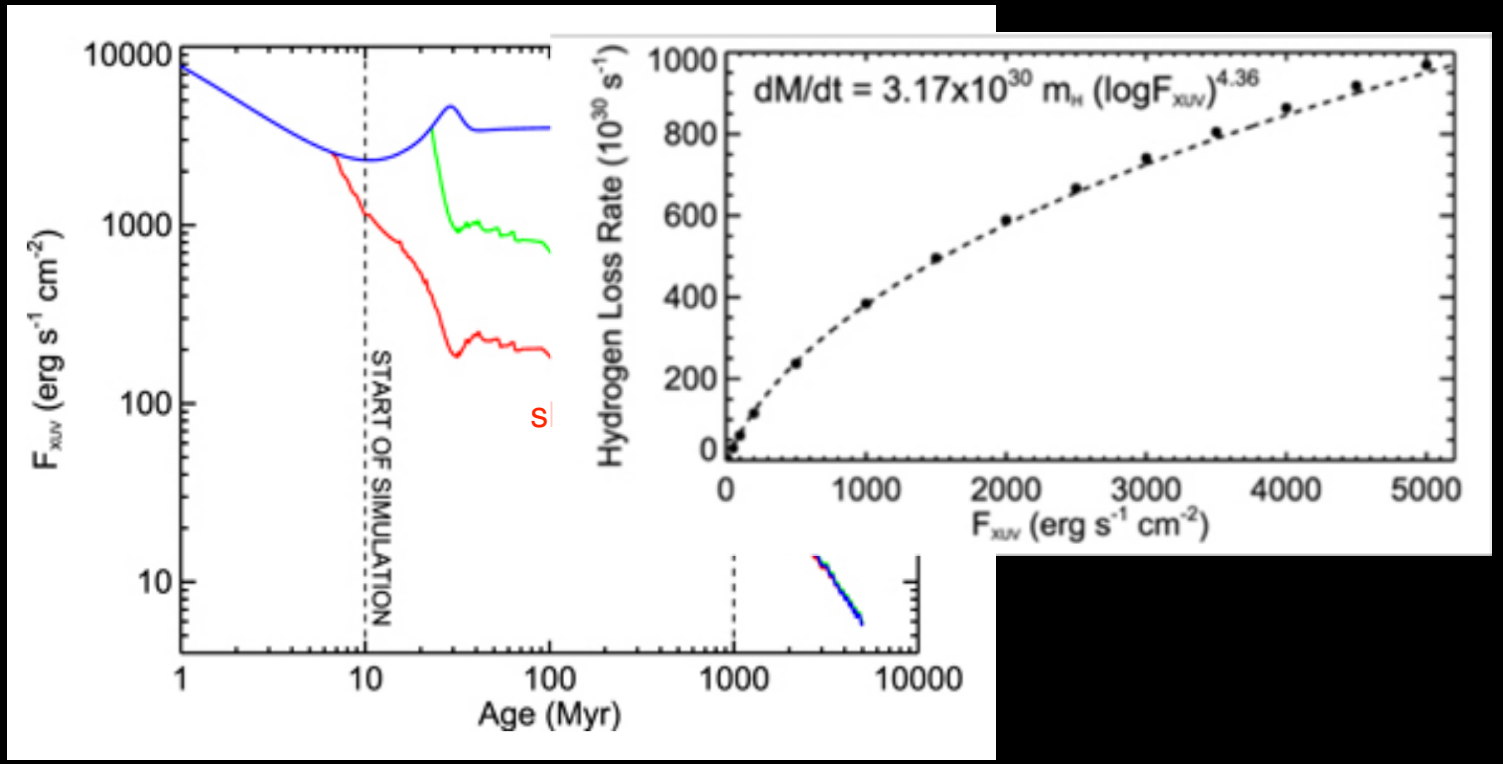


Ribas et al. 2005, ApJ, 622, 680

Potential Exoplanet Applications of Lynx

How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly



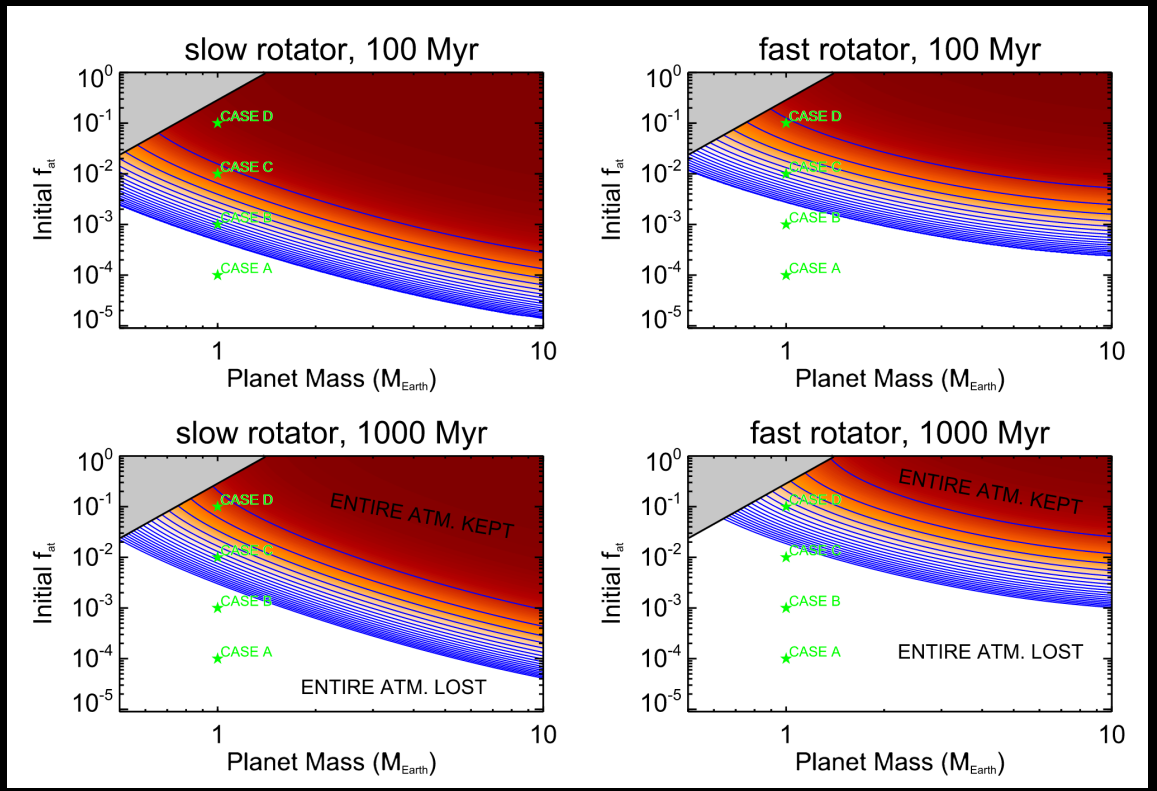
Johnstone et al. (2015)

X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly



Johnstone et al. (2015)

X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly

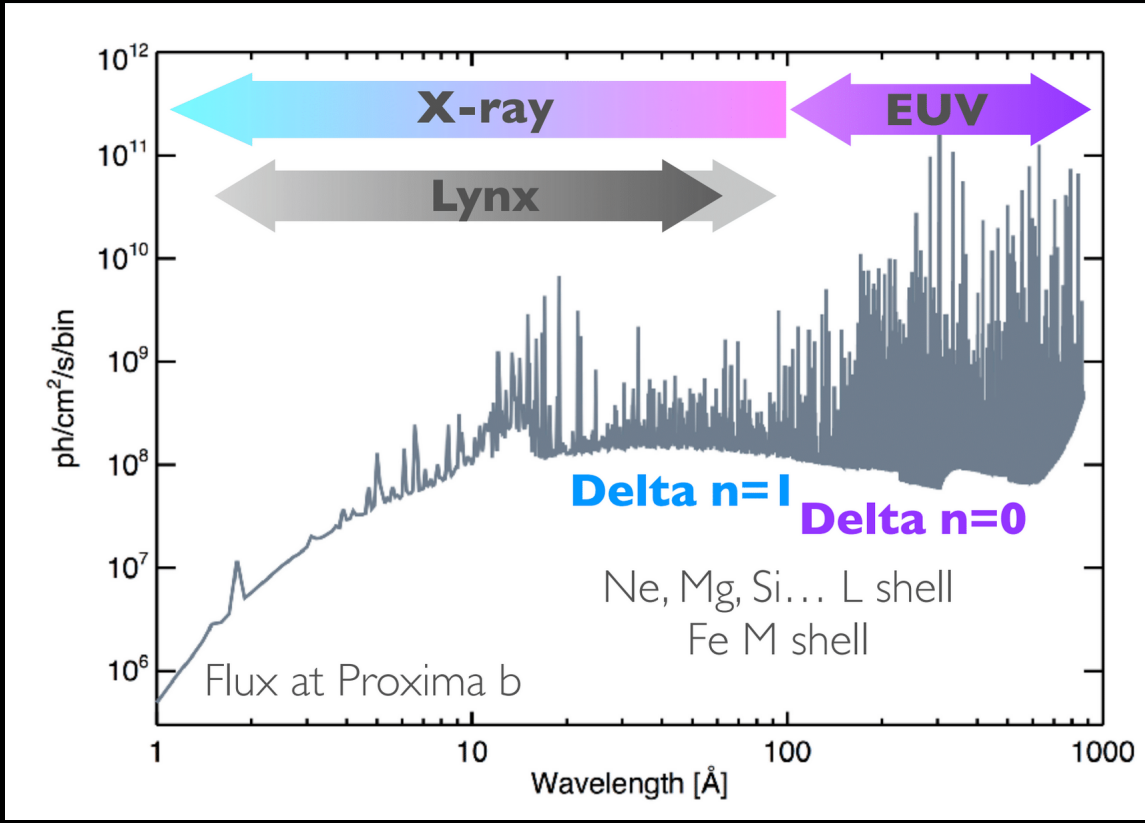


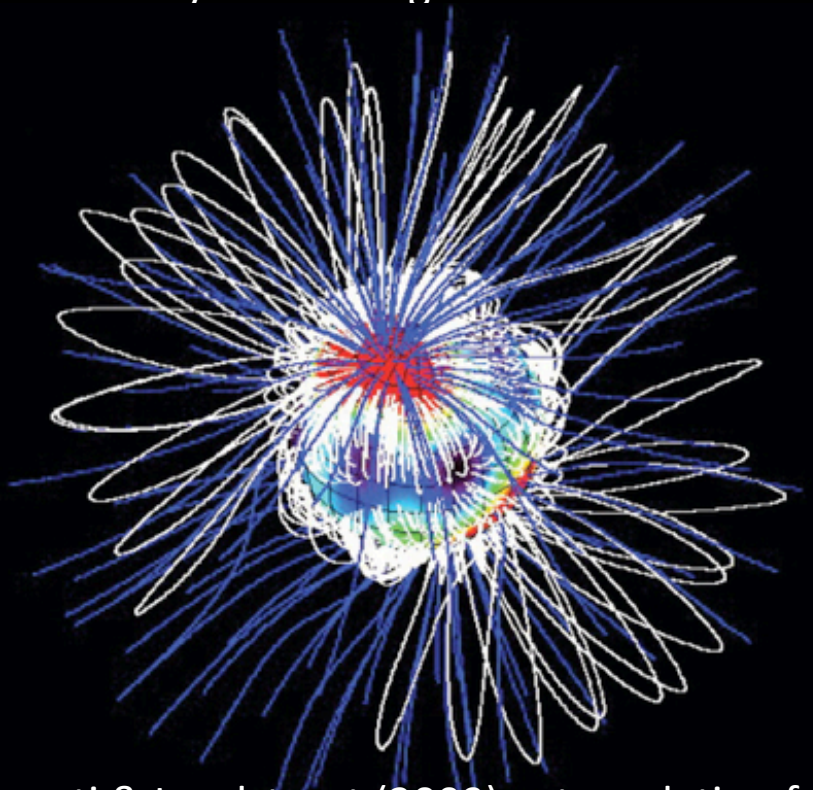
Figure courtesy J. Drake

X-RAY OBSERVATORY LYNX

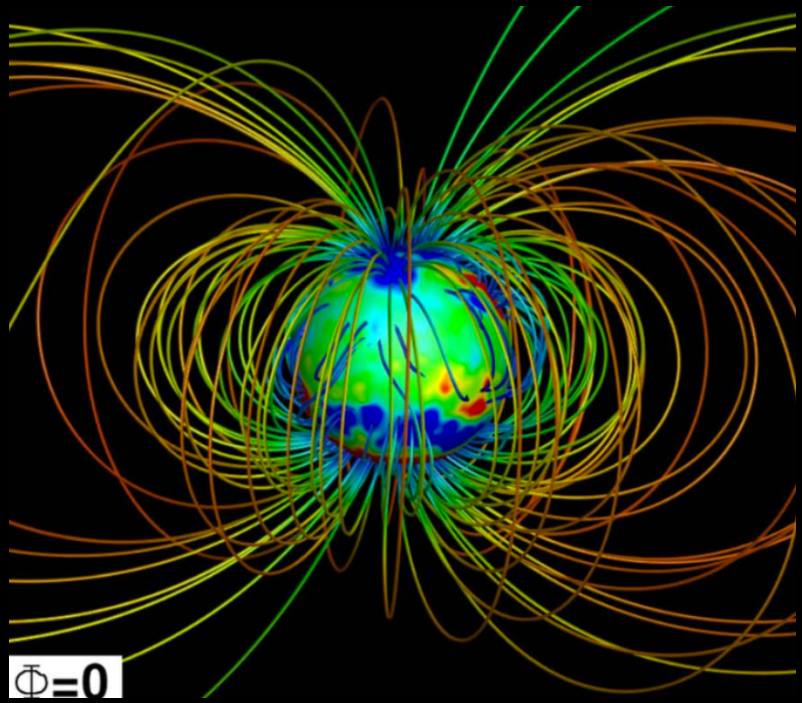
Potential Exoplanet Applications of Lynx

How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly



Donati & Landstreet (2009) extrapolation from photospheric magnetic field



Cohen et al. (2017) dynamo simulation

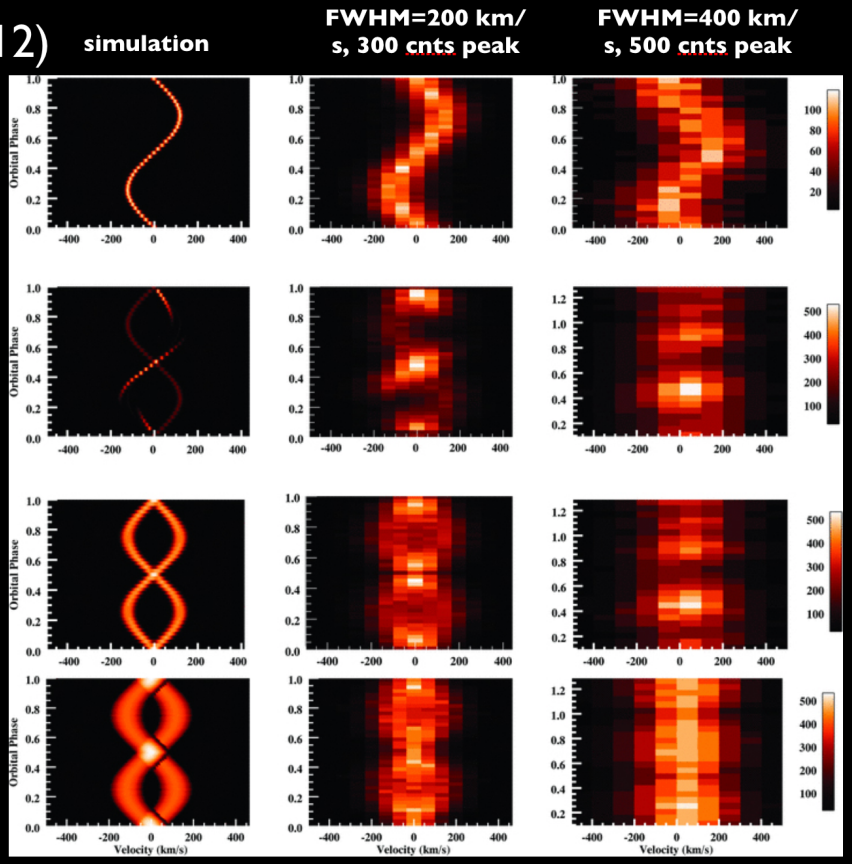
X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

How does the coronal emission of stars affect exoplanets?

- Stellar twins are not magnetic twins; star's X-ray emission at early ages is a much larger factor in planetary irradiation
- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly

Hussain et al. (2012)

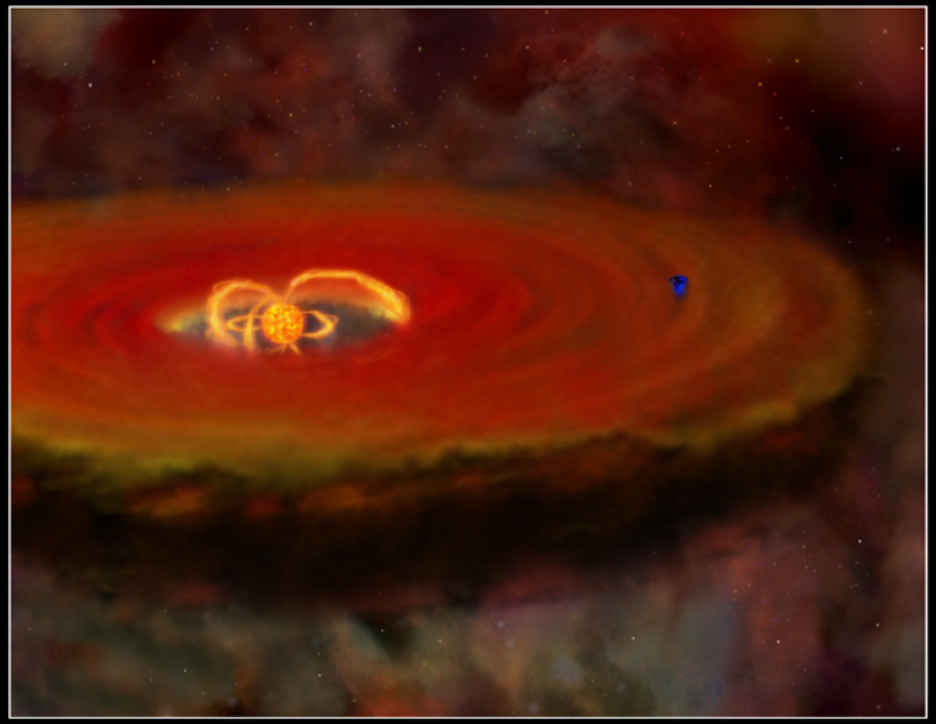


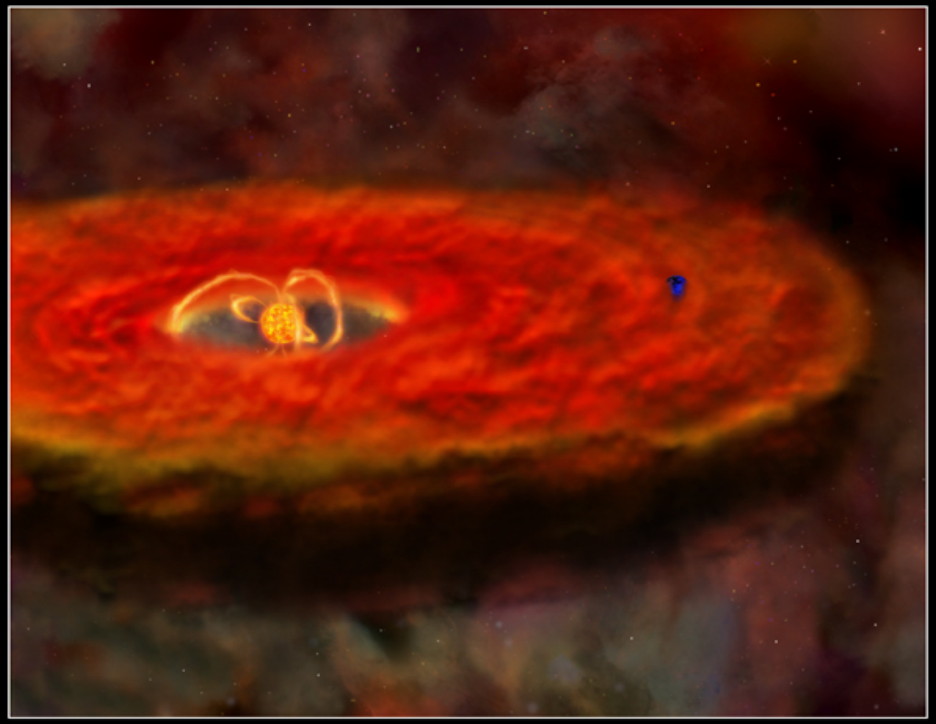
X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

How do the characteristics of flares change with time and what impact does this have on exoplanet conditions?

- Systematic change of T_{max}, E_{flare}, $L_{x,max}$ on flares of stars with varying mass, age, magnetic configuration as input to evolution of planetary irradiation
- Influence of energetic particles inferred from line profiles



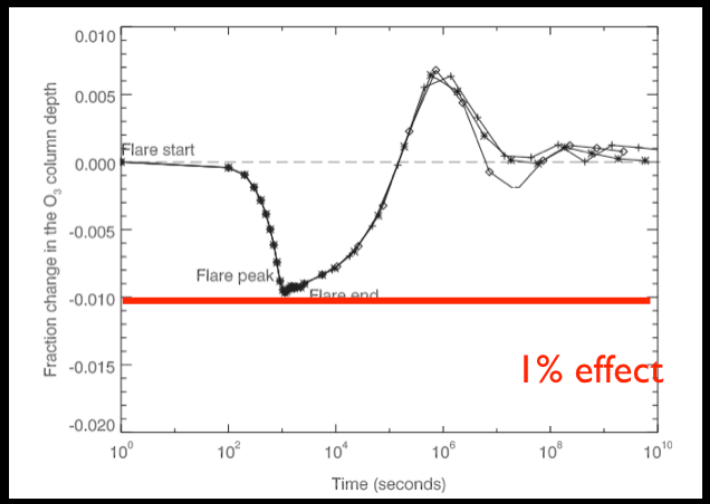


X-RAY OBSERVATORY LYNX

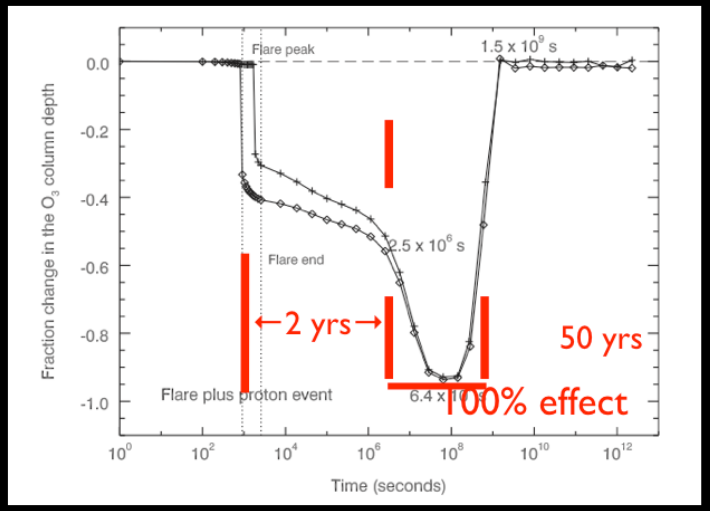
Potential Exoplanet Applications of Lynx

How do the characteristics of flares change with time and what impact does this have on exoplanet conditions?

- Systematic change of T_{max}, E_{flare}, $L_{x,max}$ on flares of stars with varying mass, age, magnetic configuration as input to evolution of planetary irradiation
- Influence of energetic particles inferred from line profiles



A UV flare only has a 1% effect on the depletion of the ozone layer of an Earth-like planet in the habitable zone of an M dwarf



A UV flare + proton event (>10 MeV) inferred from scaling from solar events, results in complete destruction of the ozone layer in the atmosphere of an Earth-like planet in the habitable zone of an M dwarf

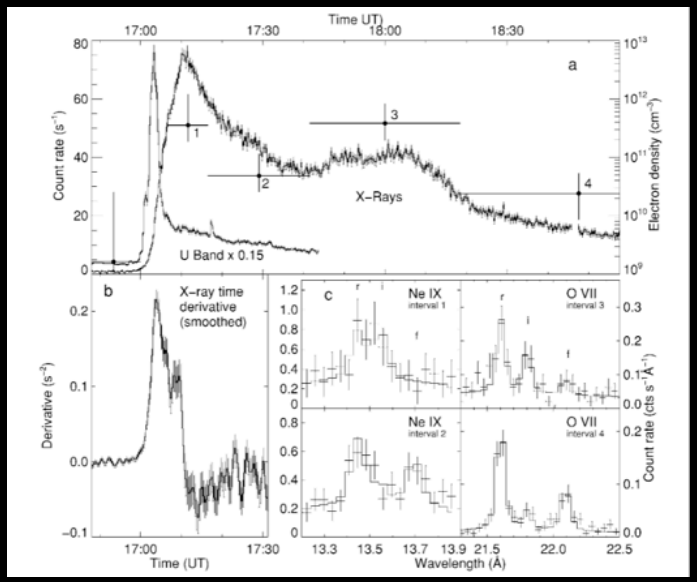
Segura et al. (2010)

X-RAY OBSERVATORY LYNX

Potential Exoplanet Applications of Lynx

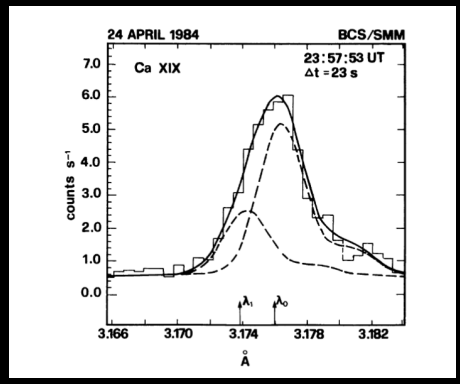
How do the characteristics of flares change with time and what impact does this have on exoplanet conditions?

- Systematic change of T_{max}, E_{flare}, $L_{x,max}$ on flares of stars with varying mass, age, magnetic configuration as input to evolution of planetary irradiation
- Influence of energetic particles inferred from line profiles



Large flare on Proxima
Güdel et al. (2002)

Antonucci et al. (1990)



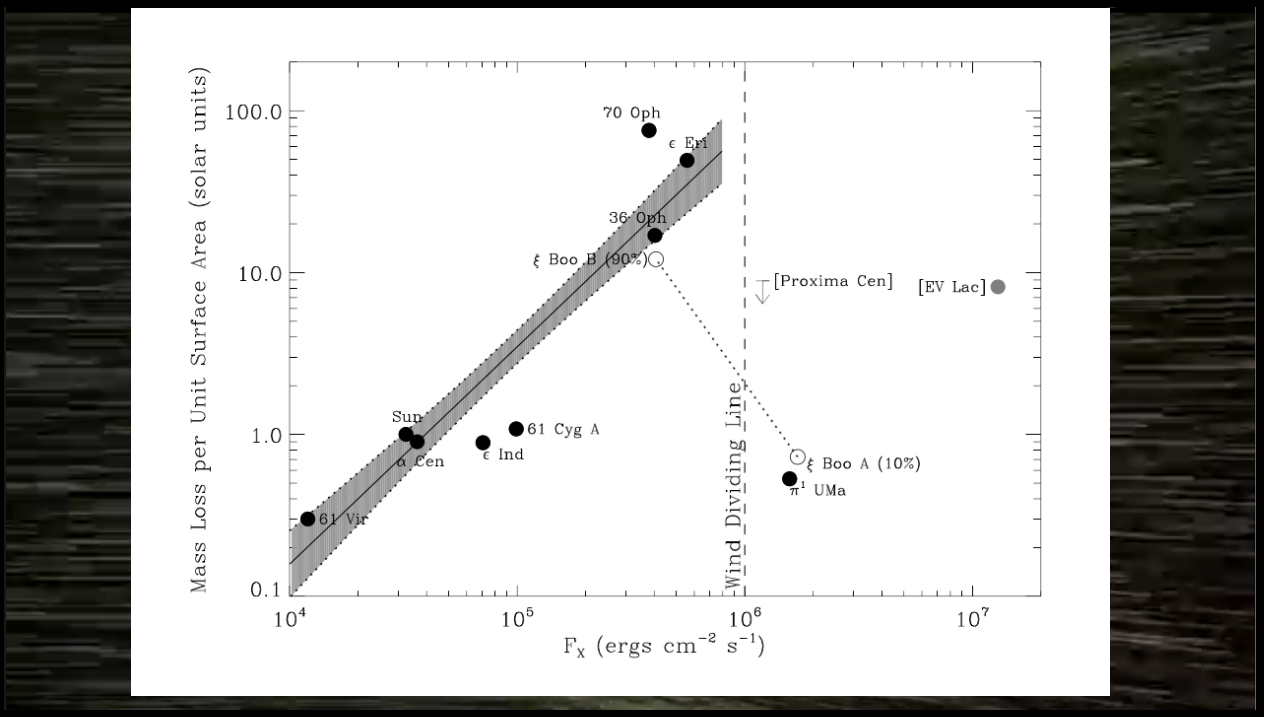
- Blueshifts in solar flares up to several hundred km/s, coincide with start of nonthermal hard X-ray emission from accelerated particles (Antonucci et al. 1990)
- Peak in nonthermal line broadening occurs at same time as maximum amount of hard X-ray emission (Antonucci et al. 1982)

X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

How do stellar winds change with time and what impact does this have on exoplanet conditions?

- Stellar wind mass loss critical to atmospheric escape process
- Detect charge exchange emission from nearest ~20 stars to constrain $\dot{M}$
- Coronal mass ejections play an important role in potential habitability; need a way to constrain them



Credit: NASA MAVEN mission

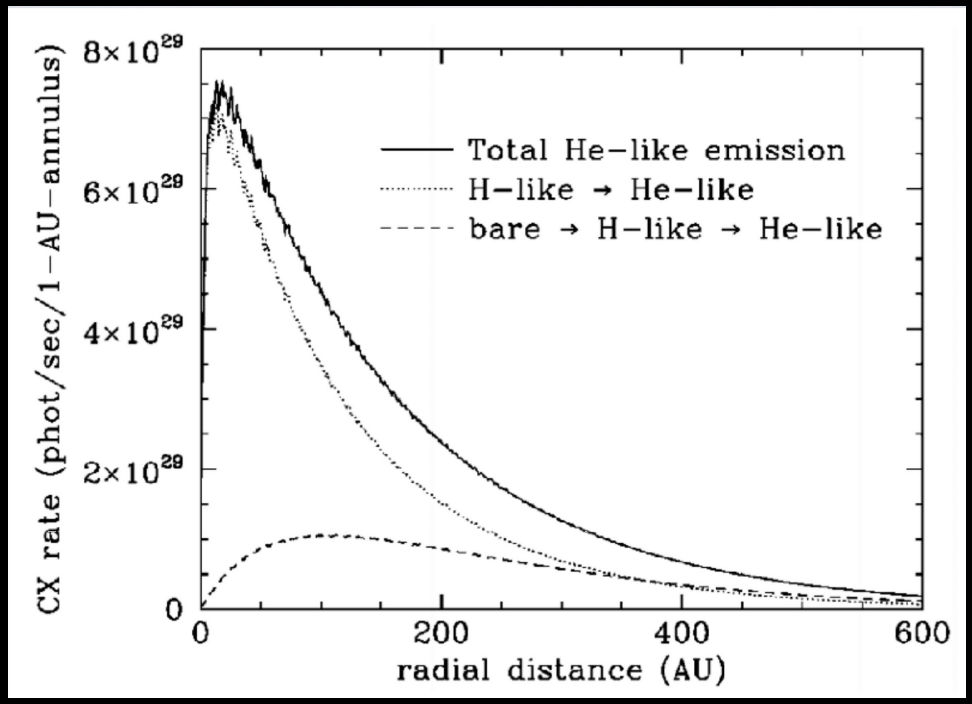
Wood et al. (2004) indirect measures of stellar mass loss

X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

How do stellar winds change with time and what impact does this have on exoplanet conditions?

- Stellar wind mass loss critical to atmospheric escape process
- Detect charge exchange emission from nearest ~20 stars to constrain $\dot{M}$
- Coronal mass ejections play an important role in potential habitability; need a way to constrain them



Wargelin & Drake (2001)
Upper limit on mass loss rate of Proxima from charge-exchange emission from interaction of stellar wind with ISM

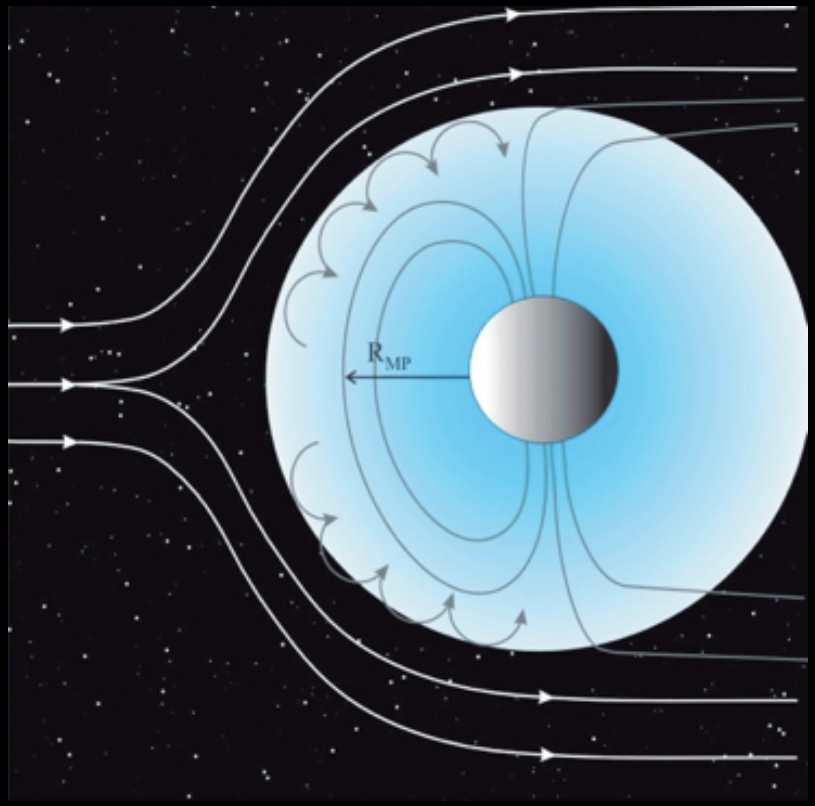
Requires spatial resolution <0.5” to resolve CX from central point source
Applicable to ~20 nearby stars.

X-RAY OBSERVATORY
LYNX

Potential Exoplanet Applications of Lynx

How do stellar winds change with time and what impact does this have on exoplanet conditions?

- Stellar wind mass loss critical to atmospheric escape process
- Detect charge exchange emission from nearest ~20 stars to constrain $\dot{M}$
- Coronal mass ejections play an important role in potential habitability; need a way to constrain them



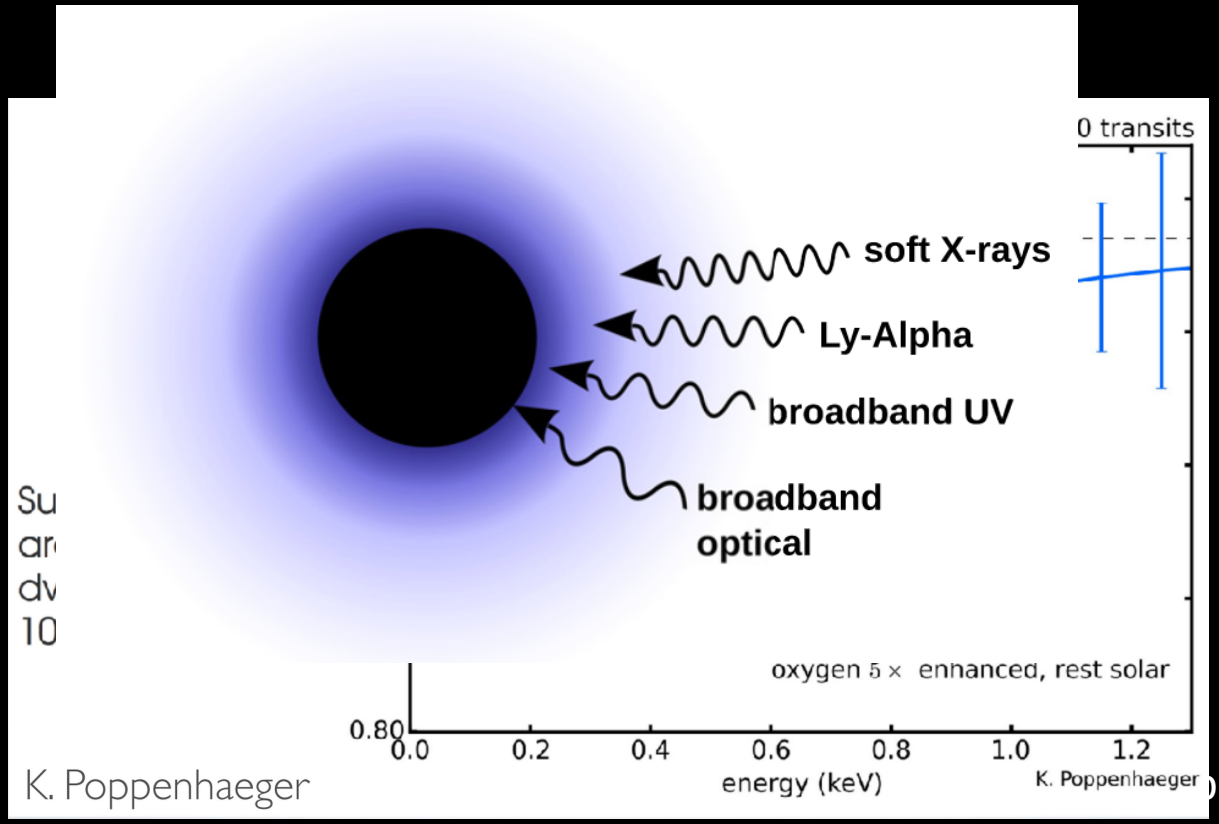
Lynx capabilities give several ways to detect CMEs:

1. Changes in column density during a flare
2. Detection of coronal dimming
3. Velocity signatures in the line profile

Potential Exoplanet Applications of Lynx

How does the size of the exoplanet's atmosphere contribute to its mass loss?

- Planetary $\dot{M}$ depends on F_{XEUV}
- Larger estimated mass loss than if the planetary atmosphere is not extended
- Direct measures of atmospheric height



X-RAY OBSERVATORY
LYNX

Conclusions

Lynx's observatory class science pillars focus on using X-rays to understand processes important for Physics of the Cosmos, Cosmic Origins, as well as Exoplanetary Science

Lynx will be a major leap forward in X-ray capabilities, which will be unmatched by other future large X-ray missions

Lynx addresses questions relevant to furthering our understanding of the energetic side of stellar ecosystems, constraining the impact of stellar activity on extrasolar planets and habitability:

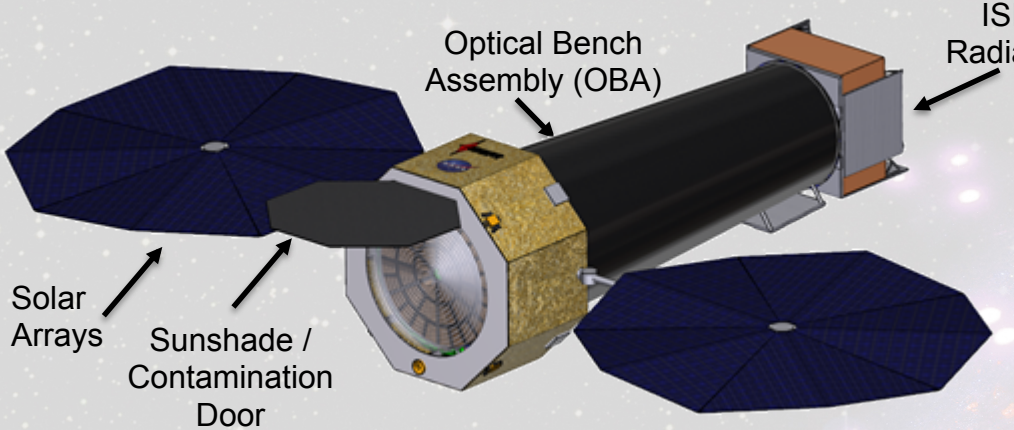
- ✓ Where do planets form? How do they migrate?
- ✓ How does the coronal emission of stars affect exoplanets?
- ✓ How do the characteristics of flares change with time, and what impact does this have on exoplanet conditions?
- ✓ How do stellar winds change with time, and what impact does this have on exoplanet conditions?
- ✓ How does the size of the exoplanet's atmosphere contribute to its mass loss?

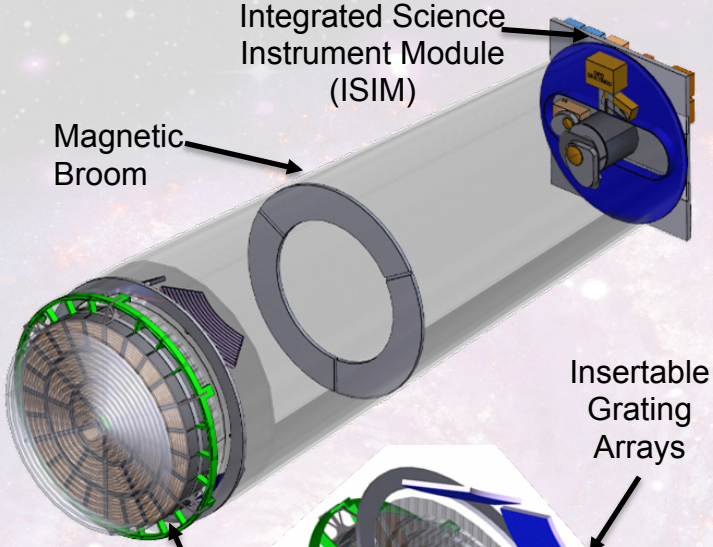
Potential Exoplanet Applications of Lynx

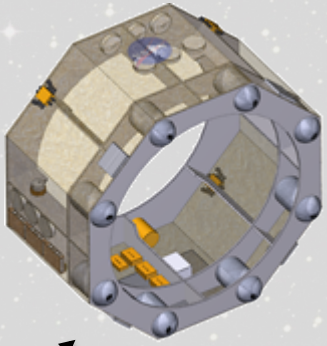
End

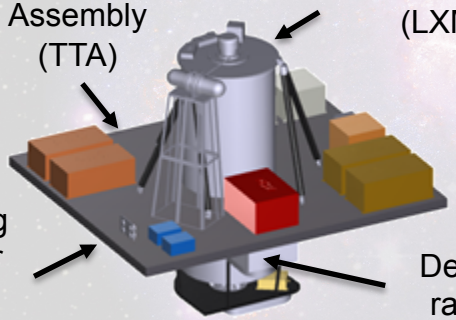
Lynx Observatory

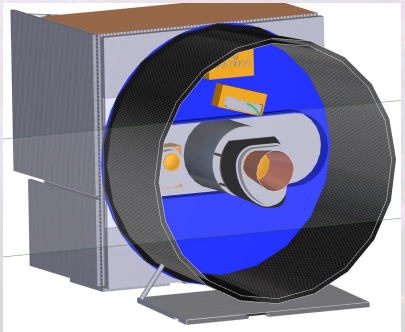
X-RAY OBSERVATORY
LYNX











Under Refinement!

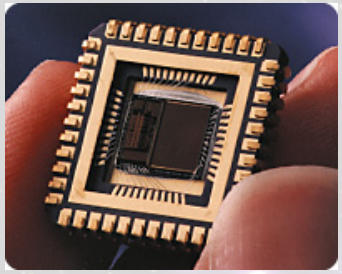
Science Driven Instrument Requirements

X-RAY OBSERVATORY LYNX

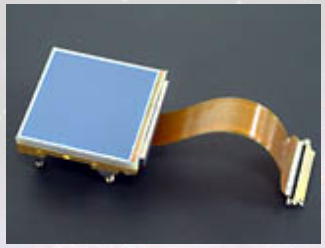
High-Definition X-ray Imager

Optimized for deep survey science

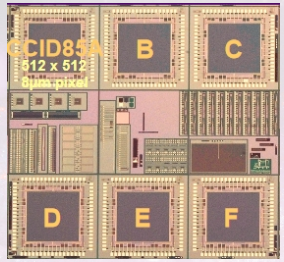
- Silicon sensors with ~ 0.3″ pixels
- FOV ≥ 20′×20′
- Δ *E* ~ 100 eV over 0.1–10 keV band
- High frame rates to minimize pile-up.



Monolithic CMOS



Hybrid CMOS



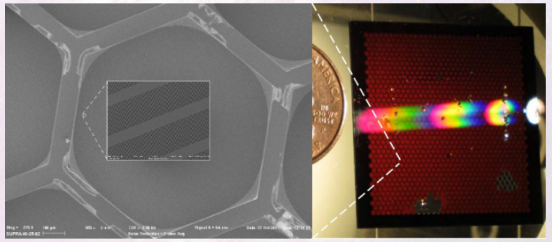
Digital CCD with CMOS readout

X-ray Grating Spectrometer

Detail outflow velocities and mass loss rates to provide information on matter and energy feedback in accreting galaxies.

Map the unobserved, large fraction of baryons that likely exists in the hot phase of the intergalactic medium.

Off-Plane Grating Array



Critical Angle Transmission – Grating Array

- Resolving power λ/Δλ > 5000
- Effective area > 4000 cm^2 covering X-ray emission and absorption lines of C, O, Mg, Ne, and Fe-L.